PCT/AU2004/001379

Patent Office
Canberra

I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003905511 for a patent by VENTRACOR LIMITED as filed on 09 October 2003.

WITNESS my hand this
Eighteenth day of October 2004

J. Billingsley

JULIE BILLINGSLEY
TEAM LEADER EXAMINATION
SUPPORT AND SALES

P/00/009

Regulation 3.2

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Invention Title: **IMPELLER**

The invention is described in the following statement:

Our Ref: 031057

Field of the Invention

The present invention relates to improvements relating to the design of implantable blood pumps.

Background of the Invention

Cardiovascular disease remains a leading cause of death in the developed world, responsible for more than 40% of deaths in Australia and in the United States. Annual diagnoses of new cases of heart failure in the United States have reached 550,000, leading to a population of approximately 4.7 million people afflicted by the disease; annual cost estimates for heart failure treatment range from USD$10 billion to $38 billion. Cardiac transplantation provides substantial benefit for patients with severe heart failure, however there is a gross disparity between the numbers of potential recipients (800,000 p.a. worldwide) and suitable transplant donors, approximately 3,000 p.a. worldwide. Consequently there is a clear need for development of an effective heart support device.

In the past, Ventricular Assist Devices ('VADs') or Left Ventricle Assist Devices ('LVADs') have been developed to provide support to the heart and are typically used for temporary (bridge-to-transplant and bridge-to-recovery) and permanent (alternative-to-transplant) support of patients. Generally, support for the left ventricle with an assist device (rather than a total artificial heart) is sufficient to restore cardiovascular function to normal levels for patients with terminal congestive heart failure. As a consequence of the shortage of transplants, there is a focus on long term alternative-to-transplant support in device development. The initial VADs developed were pulsatile (implanted and external to the body) and these have demonstrated enhanced survival and quality of life for patients with end-stage heart

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

failure compared with maximal medical therapy. However these devices are generally large, cumbersome, inefficient, prone to mechanical failure and costly.

Additionally, recent evidence suggests that early intervention with mechanical support for the heart using a VAD can enable recovery of the myocardium, to the extent that the VAD can be removed. VADs have the potential to provide the patients with a far better quality of life than any previously available options.

It has been noted that continuous flow rotary VADs are generally simpler, smaller and more reliable, as well as cheaper to produce, than the earlier pulsatile systems. For this reason, continuous flow centrifugal devices, such as the VentrAssist™ LVAD, have emerged as the definitive forms of technology in the field of cardiac assistance.

The object of the present invention is to primarily improve overall blood pump design so as to increase safety and reliability.

Brief description of the invention

Accordingly, in one broad form of the invention there is provided a rotary blood pump including: a housing, wherein said housing includes a housing cavity, an inlet and an outlet; at least one support feature; an impeller, wherein said impeller includes at least one blade attached the support feature and positioned within said cavity and, when in use, said impeller is urged to rotate by rotating magnetic field and thereby pump blood from said inlet through cavity to the outlet, and wherein said support feature promotes dimensional stability within the impeller.

Preferably said support feature reinforces the dimensional stability of said impeller.

Preferably said support feature includes at least one support ring.

Preferably the support feature includes two support rings.

Preferably at least one support feature is attached to a position proximate to outermost point of a side of each blade.

Preferably at least one support feature is attached to a position proximate to innermost point of a side of each blade.

Preferably said impeller is at least partially hydrodynamically suspended, in use, within said housing cavity.

Preferably said impeller includes at least one hydrodynamic bearing attached to an outer surface of said impeller.

Preferably said hydrodynamic suspension radially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

Preferably said hydrodynamic suspension axially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

Preferably said hydrodynamic suspension radially and axially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

Preferably said impeller includes at least one permanent magnet.

Preferably said pump includes a three phase motor formed by mounting electric coils on or about said housing.

Preferably magnets which form part of the impeller are caused to rotate in the rotating magnetic field produced by the electric coils

Preferably said pump is suitable for implantation within a patient.

Preferably said impeller includes a shaft.

Preferably said pump is an axial flow pump.

Preferably said pump includes an underhung volute positioned proximate to the outlet.

Preferably said pump is a radial flow pump.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

Preferably said pump is a diagonal flow pump.

Preferably said impeller includes at least one blood channel.

In a further broad form of the invention there is provided a rotary blood pump, the impeller for which includes at least 2 bearing surfaces and 2 channels therebetween, which in use, allow fresh blood to flow into the bearing gap between corresponding bearing surfaces on the impeller and pump cavity thereby reducing the residence time of blood in the bearing gap and thereby reducing haemolysis

Preferably there is provided a rotary blood pump, the impeller for which includes blades which, in use, urge fluid through the pump and support features and wherein the surfaces of the support features are arranged so as to provide means of hydrodynamic bearing for the impeller.

Preferably the blades also have surfaces arranged so that, in use, they provide a means of hydrodynamic bearing for the impeller.

Preferably there is provided an impeller for a rotary pump; said impeller comprising a plurality of hydrodynamic support surfaces spaced apart by and mechanically linked by support features or support units.

Preferably each support feature provides mechanical support against flexing of adjacent hydrodynamic support surfaces.

Preferably said support features or support units incorporate hydrodynamic bearing surfaces.

Preferably said hydrodynamic support surfaces are in the form of blades.

Preferably said support feature is dimentioned to allow movement of fluid between said support feature and said hydrodynamic support surfaces when said impeller is rotated within a housing.

In yet a further broad form of the invention there is provided a pump incorporating a housing; said housing including internal wall surfaces which interact with the above described impeller during rotation of said impeller within said housing whereby said impeller is supported in at least one degree of freedom by hydrodynamic forces generated by relative rotation of said impeller with respect to said internal wall surfaces.

Preferably said pump is adapted to the pumping of blood.

Brief description of the drawings

Embodiments of the present invention will now be described with reference to the accompanying drawings wherein:

Figure 1 is a cross-sectional view of a further preferred embodiment of the present invention featuring an impeller;

Figure 2 is a top view of the embodiment shown in figure 1;

Figure 3 is a cross sectional view of a preferred embodiment of the present invention;

Figure 4 is a perspective view of a further preferred embodiment of an impeller;

Figure 5 is a cross sectional view of a further preferred embodiment of the present invention;

Figure 6 is a top view of the preferred embodiment depicted in figure 5; and

Figure 7 is a perspective view of a further preferred embodiment of the present invention featuring an impeller;

Figure 8 is a top perspective view of a further preferred embodiment of the present invention featuring an impeller;

Figure 9 is a bottom perspective view of the embodiment shown in figure 8; and

Figure 10 is a top perspective view of a further embodiment.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

Brief description of the preferred embodiments

The pump assemblies according to various preferred embodiments to be described below, all have particular, although not exclusive, application for implantation in a patient. In practice, these pump assemblies may be used in mammalian patients to assist a patient's heart to pump blood. In particular, these pump assemblies may be used to reduce the pumping load on a patient's heart to which the pumping assembly is connected. There may be other applications suitable for use with embodiments of the present invention and these may include use as: perfusion pumps, applications requiring the pumping of fragile fluids, external short term surgical blood pumps, and/or long term implantable blood pumps.

Preferably, the pump assemblies are suitable for use or applications as an implantable blood pump. These blood pumps may also be suitable for long term patient implantation.

In practice preferred embodiments of the present invention may be performed by placing the blood pump entirely within the patient's body and connecting the pump between the apex of the left ventricle of the patient's heart and the ascending aorta so as to assist left side heart function. It may also be connected to other regions of the patient's circulation system including: the right side of the heart and/or distal regions of a patient such as the femoral arteries or limbs.

In this first preferred embodiment, the blood pump includes an impeller which is fully sealed within the pump body. Preferably this blood pump may not require a shaft extending to the pump body to support the impeller. The impeller is preferably suspended, in use, within the pump body by the operation of hydrodynamic forces imparted as a result of the interaction between the impeller, when rotating, the internal

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

pump walls and the pumping fluid, wherein said fluid is urged from an inlet of the pump to an outlet of the pump.

Preferably the impeller is positioned within a cavity formed in the housing at a position between the inlet and the outlet. The impeller, in this embodiment, includes a plurality of blades and a blade support means. When the impeller is rotated and the cavity contains fluid, the blades produce a continuous pumping motion on the blood.

Preferably the impeller is urged to rotate, in use, by an electric motor. In a preferred embodiment, the electric motor includes several sets of electrical coils mounted on or about the housing and a plurality of permanent magnets embedded or encased within the blades of the impeller. When in operation, the electric coils sequentially energise and exert an electromagnetic force on the impeller. This electromagnetic force affects the permanent magnets. If the pump is properly configured, the sequential energising of the electric coils will cause the impeller to rotate. Preferably, the electric coils may be mounted in an axial orientation, in relation to the axis of rotation of the impeller, to minimise space. However the electric coils may also be mounted radially in respect of the axis of rotation of the impeller.

Alternately, other forms and configurations of electric motors are possible to incorporate into the embodiments of the present invention. Other forms may include an ordinary electric motor connected to a pivot shaft upon which the impeller is mounted.

Additionally in a preferred form an outer surface of the impeller forms a fluid restriction with the interaction of the inner pump walls or cavity walls. This fluid restriction imparts a hydrodynamic force upon the impeller pushing the impeller away from the region of fluid restriction. Preferably these restrictions are balanced around

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

the outer surface of the impeller so as to generate a hydrodynamic suspension effect on the impeller, when rotated within a fluid.

The hydrodynamic force imparted, in the preferred embodiment, acts simultaneously in both an axial and radial direction with respect to the orientation of the impeller. Other configurations of the pump are possible, which may allow the hydrodynamic force to be imparted in only an axial or a radial direction. All embodiments may be additionally or supplementally supported by active or passive magnetic suspension.

A preferred embodiment of the present invention, which is used as a ventricular assist device, operates at an impeller rotation speed between 1500 rpm to 4000 rpm. The preferred outer blade diameter is 40mm, outer housing average diameter is 60mm and the housing axial length is 40mm.

It is important to note that for the embodiments to function safely and reliably, when in use, preferred embodiments of the present invention will include features that limit thrombogenesis and haemolysis and which add to the mechanical reliability of the pump. Preferably, the impeller of the preferred embodiments may include at least some amount of dimensional stability to prevent the blades and/or impeller changing its shape or configuration, in situ. Small dimensional changes in the shape or configuration that may occur from warping or twisting of the impeller and/or housing and occur naturally through regularly use of the pump.

This warping or twisting of the impeller and/or housing may preferably be avoided or at least addressed, as the subsequent dimension changes may affect the pumping efficiency of a pump and as well as affecting the suspension of the impeller. This is particularly true in pump designs which include hydrodynamic bearings and/or

active magnetic bearings. Small changes in dimensions of the impeller may result, in the most extreme cases, in complete pump failure.

Preferably, the impellers and/or housing may be reinforced to improve the overall dimensional stability of the impeller and/or housing.

A preferred embodiment of an impeller in accordance with the present invention is depicted in figure 1. An impeller 5 is shown. The impeller 5 includes five distinct blades 4 having two ends. One of the said ends may be attached to a shaft 1. The opposed end of each blade 4 may be fixably attached to a circular support ring 2. Preferably the support ring 2 includes one or more hydrodynamic bearings 3. The shaft 1 is preferably centered within the periphery of the impeller and is orientated in an axial direction. The impeller may, in use, rotate about the axis designated by the shaft. The circular support ring 2 may occur in different shapes and configurations. However the circular arrangement depicted in figure 1 is the preferred configuration.

Preferably, when the impeller is rotated, the blades 4 push a fluid, for example blood, in an axial direction relative to the impeller and generally towards an outlet. The support ring 2 may have a generally rectangular cross section excluding the portions which form the hydrodynamic bearings. This generally rectangular cross section of the support ring 2 may provide that generally square, rectangular or circular in cross-section magnets may be easily inserted within the support ring 2 at regular or spaced intervals. It may be easier to manufacture magnets in a generally square, rectangular or circular cross-section shape. In a particular form the support ring 2 may be of hollow construction to minimise weight and/or to reduce complexity of construction.

The magnets inserted within the circular ring support 5, in use, may cooperate with the electromagnetic stators located on or around the housing in such a way as to

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

form a hydrodynamic bearing motor. Preferably, this motor may be of a three phase configuration. The magnets inserted within the circular support ring 2, in use, may also cooperate with electromagnets to aid in electromagnetic support of the rotor in at least one degree of freedom.

The blades of this embodiment are generally thin and arcuate in shape and may incorporate features to minimise drag and/or shear forces.

In the embodiment depicted in figure 1, the impeller 5 includes four hydrodynamic bearings 3, of which three bearings are visible in this view. The surface of hydrodynamic bearings 3 is generally angled between 0° and 90° to cooperate with an inner surface of a housing to generate a hydrodynamic force away from the inner surface. In a preferred form the combined effect of these hydrodynamic bearings is to hydrodynamically suspend the impeller within the housing, when in use. A preferred angle for the hydrodynamic bearings is approximately at 45°.

Figure 2 depicts the abovedescribed impeller 5 from a top view. In this view, the impeller 11 includes a support ring 10, a shaft 6 and five blades 9. It is preferable to include five blades within this embodiment, this embodiment may alternately include any amount of blades of variable configuration so long as the impeller is capable of being stable and/or balanced, when rotated.

Additionally in this view, four permanent magnets 7 are shown in this embodiment. These magnets may be embedded within the impeller. The present view displays the magnets for general description purposes and to show the general preferred locations or positions of magnets when embedded within the support ring of the impeller. The magnets may be placed in any location within the support ring 10. However the optimal positions for a four magnet configuration are shown in figure 2.

It may be important to balance the positions of the magnets to increase impeller stability and balance.

It is preferable to include four permanent magnets within the support ring 10 however other amounts of magnets may also achieve the desired result. The function of these permanent magnets is to interact with electromagnetic stator coils mounted in or outside the housing. The interaction between the coils and the permanent magnets is such that, when in use, the impeller is magnetically urged to rotate axially within the housing.

As shown in figure 2, the hydrodynamic bearings 8 are mounted on the upper surface of the support ring 10. In this embodiment, there are also hydrodynamic bearings mounted on the reverse side of the impeller, which are not shown in figure 2. These bearings provide a balance net thrust force which is capable of hydrodynamically suspending the impeller 11 in the pump housing, when in use.

Please note that both impellers 5 & 11 depicted in figures 1 & 2 include increased dimensional stability. In these embodiments the increased dimensional stability is applied by the generally square cross-section of the support rings 2 & 10. The support rings 2 & 10 are joined to the blades 4 & 9 in this configuration to prevent or limit the amount or severity of twisting, warping and/or other undesirable dimensional deformation.

Figure 3 shows a preferred embodiment is a blood pump 15 including a housing 23 and an impeller 18, which is also depicted in figures 1 & 2. The blood pump 15 includes an inlet 22 and an outlet 21 formed through a housing 23. Between the inlet 22 and the outlet 21 is pumping cavity 14, which allows fluid communication throughout the pump, when in use. Preferably within this cavity 14 is an impeller 18 comprising a support ring 24, a shaft 19, blades 16 (not visible in figure 3) and

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

hydrodynamic bearings 25. In this embodiment, there is preferably five blades included within the impeller and it this blades that supply pumping motion to the fluid, to be pumped when in use.

Preferably, the impeller 18 may be mounted within said pumping cavity 14. The preferred housing 23 also may include machined surface on the surface of the pumping cavity. This machined surface may include an upper inner surface 12 of the cavity 14, middle inner surface 13 of the cavity 14 and a lower inner surface 62 of the cavity 14. Preferably, the upper inner surface 12, middle inner surface 13 and/or the lower inner surface 62 cooperate with at least a portion of outer surfaces of the impeller to form, in effect, hydrodynamic bearings. In particular, these portions of the surfaces include the outer surface of the support ring 24 and/or the hydrodynamic bearings 25 mounted on the support ring.

Preferably, when the impeller is rotated, the hydrodynamic bearings 25 may cooperate with a proximate portion of the angular inner surfaces 12 & 62 of the pumping cavity 14. Thereby, when fluid passes through a gap 20 located between the hydrodynamic bearing 25 and inner surface 62 of the housing cavity 14, the impeller 18 experiences a hydrodynamic thrust force. This thrust force acts upon the impeller 18 in a direction away from the inner walls of the housing. The net force of all of the hydrodynamic bearings may preferable result in the impeller being partially or exclusively hydrodynamically suspended within the housing.

In the embodiment shown in figure 3, the impeller includes an axial and an radial component to the hydrodynamic thrust force as a result of the hydrodynamic bearing 25 being angular.

Additionally, blood pump 15 is in an axial flow configuration and this may also be preferable. The impeller, in use, is magnetically urged to rotate by the electro-

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

magnetic interaction between permanent magnets (not shown in figure 3) embedded or encased within the support ring 24 and the electro-magnetic stator coils 17 mounted in a radial orientation in respect the axis of rotation of the impeller 18. Preferably there are three electric coils 17 but the amount of may be amended without generally affecting the functionality of this embodiment so long as there are at least two said coils. Please note that other coil configurations may also be used and these configurations may include axial mounting configurations.

On the support ring 24 is preferably attached to four sets of hydrodynamic bearings 25 mounted on both sides of the impeller 18. These hydrodynamic bearings 25 have a generally wedge shaped side profile so as to generate a hydrodynamic force when rotated within a complementary housing cavity 23. Please note that the number and size of the hydrodynamic bearing may be also amended without departing from the scope of the present invention. Other configurations of hydrodynamic bearings may include at least one hydrodynamic bearing mounted on each side of the impeller and said bearing may run along the entire length of the support ring.

An alternate pump design is depicted in figure 5. The blood pump 37 includes a similar configuration to that shown in the pump 15 in figure 3. Pump 37 differs from pump 15 in that the resulting pump is a mixed or radial flow pump as the blood or fluid path is encouraged to flow into a volute 33. Pump 37 includes an underhung volute positioned between a pump housing cavity 38 and an outlet 32. Generally, the fluid may flow from an inlet 26 into the pump housing cavity 38 formed by the housing 31. The fluid, in use, may be then pumped into the underhung volute 33 by the blades of the impeller 35 (not visible in figure 5) pushing pumping fluid, in use, along a path 30, then around the volute 33 and finally exiting through the generally tangential outlet 32.

Preferably, the impeller includes a support ring 36 which is attached to the blades of the impeller 35 and at least one hydrodynamic bearing 40. The hydrodynamic bearings 40 may be constructed to balance the hydrodynamic thrust forces to suspend the impeller away from the inner surfaces of the housing, in use. The support ring 36 may include permanent magnets which interact with the electro-magnetic stator coils 39 located in a generally axial or axial/radial hybrid orientation. Please note that other orientations of the electro-magnetic electric coils 39 may also be possible without deviating from the scope of the present invention.

Figure 6 depicts the top view of a preferred pump in which electro-magnetic stator coils 41 are formed in the upper surface of the aforementioned housing 43. Please note that the pump inlet 42 is also shown. Please note in this preferred embodiment, the stator coils are mounted axially in respect of the impeller. The preferred configuration includes three sets of coils mounted on either side of the housing in axial configuration. This overall configuration will form a three phase motor and will preferably cooperate with an impeller that includes four magnetic regions or magnets.

In another preferred embodiment of the present invention an alternate impeller may be used. This alternate impeller 45 is depicted in figure 7. The impeller 45 may include four blades 48. Please note that the number of blades may be amended to suit the conditions and/or environment of the pump. Each blade may then be generally uniformly supported along its width and/or length. This support reinforces the impeller configuration and increases dimensional stability of the configuration. This is achieved in this embodiment by attaching two generally parallel support features 44 & 46 to each blade to provide even support. The impeller 45 may then experience

increased dimensional stability as the two support features 46 & 44 will cooperate to increase the rigidity of the entire preferred impeller 45.

Preferably, the support feature 44 may be attached to an outermost point on the sides of each blade and/or the support feature 46 may be attached to an innermost point on the sides of each blade. The support features may be attached between all of the blades 48.

Additionally, the support features 44 & 46 may also include relatively small blood channels 47 to increase fluid dynamics. The channels 47 also are positioned so as to reduce localised fluid pressure in the regions of the blood path proximate to the channels 47. This reduction in localised pressure may increase the safety of the use of this impeller as the likelihood of damage will be significantly reduced. Additionally, the support features 44 & 46 and/or blood channels 47 may integrally include hydrodynamic thrust bearings to assist with suspension of the impeller 45, in use, which is preferably hydrodynamic.

Please also note that the outer surfaces of the blades 48 are shaped to interact, in use, with the inner walls of a pump housing (not shown in figure 7) to generate hydrodynamic thrust forces. These thrust forces are arranged such that they act to push the impeller away from said inner walls and may hydrodynamic suspend the impeller, in use.

Additionally, in the embodiment depicted in figure 7, the lower support feature 44 includes a flattened portion 49. This flattened portion may be used to assist in mounting or fixing the impeller position when testing, measuring, and/or manufacturing.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

In figures 8 & 9, another preferred embodiment of an impeller 54 is shown. Figure 8 shows the top perspective view of this preferred impeller and figure 9 depicts the bottom perspective view of the impeller 54.

The impeller 54 is similar in configuration to the impeller 45 shown in figure 7 in that both impellers include support feature(s) 53, 44 & 46, blades 50 & 48, blood channels 51 & 47 and lack a shaft 52 & 57.

Preferably, the impeller 54 includes four blades 50 which in turn include outer surfaces which are arranged so as to produce a hydrodynamic thrust force, when in use, and rotated in a fluid within a complementary housing (not shown). These thrust forces are typically such that the net effect of the combined thrust forces is to suspend the impeller 54 within the housing, in use.

Whereas the impeller 45 shown in figure 7, depicts two distinct support features 44 & 46, the impeller 54 includes one support feature 53. Preferably, this support feature 53 extends a substantial distance along the length of the upper surface of the blades 50 and joins them in a ring formation. The extension of the support feature 53 may increase the dimensional stability of the impeller 54.

The blood channels 51 serve a similar function to the channels 47 in figure 7. They primarily serve to reduce localised pressure proximate to the leading of the impeller 54 and to allow fresh blood into the bearing gap formed between the outer surface of the rotor and inner surface of the housing thereby reducing the residence time of the blood in the gap and reducing haemolysis. Please note that it is possible to modify these channels 51 to allow them to also generate a significant hydrodynamic force, when in use.

Additionally, the impeller 54 also includes an outer side wall 55 of the impeller 54. These side walls 55 are generally axial in orientation and may include a

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

hydrodynamic bearing surface to cooperate with the pumping fluid and the inner wall of the housing, when in use. This type of hydrodynamic thrust force may primarily be radially in orientation.

A further preferred embodiment of an impeller is shown in figure 4. The impeller 28 features a shaftless design shown by a circular hole 26 at the center of the impeller 28.

The figure 4 depicts the top view of the impeller 28 wherein a support feature 27 covers a set of blades (not shown) in a manner or fashion as described and shown in figure 8. Extending from the circular hole 26 are several blood channels or grooves 29. These blood channels or grooves are arranged so as to form a hydrodynamic bearing when used in conjunction with a complementary housing. Preferably there are eight such channels in the upper surface of the impeller 28. However it should be noted that any amount of channels will work.

Preferably the channels 29 are approximately 20μm wide and 50μm deep. These channels collectively form a spiral groove bearing.

A further embodiment of the present invention is depicted in figure 10. In this embodiment, the impeller 57 is shown. This impeller 57 includes: four blades 59, wherein each includes three hydrodynamic bearing surfaces; an upper surface, a lower surface and an outer surface 56; and a generally uniform support structure, wherein said structure includes: a set of supports 60, which are preferably connected to the outer edge of adjacent blades and a secondary support 58, which is preferably attached between the innermost portion of adjacent blades.

The generally uniform support structure support the ring configuration of the blades within the impeller. The individual supports may also include hydrodynamic bearing surface and blood channels 61. As per earlier discussed embodiments, the

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

19. The pump of any one of claims 1 to 16, wherein said pump is a radial flow pump.

20. The pump of any one of claims 1 to 16, wherein said pump is a diagonal flow pump.

21. The pump of any one of claims 1 to 20, wherein said impeller includes at least one blood channel.

22. A blood pump as previously described in the specification with reference to any one of the accompanying figures.

23. A rotary blood pump, the impeller for which includes at least 2 bearing surfaces and 2 channels therebetween, which in use, allow fresh blood to flow into the bearing gap between corresponding bearing surfaces on the impeller and pump cavity thereby reducing the residence time of blood in the bearing gap and thereby reducing haemolysis

24. A rotary blood pump, the impeller for which includes blades which, in use, urge fluid through the pump and support features and wherein the surfaces of the support features are arranged so as to provide means of hydrodynamic bearing for the impeller.

25. The pump of claim 24 wherein the blades also have surfaces arranged so that, in use, they provide a means of hydrodynamic bearing for the impeller.

26. An impeller for a rotary pump; said impeller comprising a plurality of hydrodynamic support surfaces spaced apart by and mechanically linked by support features or support units.

27. The impeller of claim 26 wherein each support feature provides mechanical support against flexing of adjacent hydrodynamic support surfaces.

28. The impeller of Claim 26 or 27 wherein said support features or support units incorporate hydrodynamic bearing surfaces.

29. The impeller of any one of Claims 26 to 28 wherein said hydrodynamic support surfaces are in the form of blades.

30. The impeller of any one of Claims 26 to 29 wherein said support feature is dimentioned to allow movement of fluid between said support feature and said hydrodynamic support surfaces when said impeller is rotated within a housing.

31. A pump incorporating a housing; said housing including internal wall surfaces which interact with the impeller of any one of claims 26 to 29 during rotation of said impeller within said housing whereby said impeller is supported in at least one degree of freedom by hydrodynamic forces generated by relative rotation of said impeller with respect to said internal wall surfaces.

32. The pump of Claim 31 adapted to the pumping of blood.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

blood channels may serve to the reduce undue stresses experienced by the pumped fluid, when the impeller is in use. Generally there are two blood channels per support.

Additionally, the supports 61 & 60 are generally parallel in respect of each other. This configuration may provide generally uniform support to the impeller 57 and grant the impeller improved dimensional stability.

Preferably, the impeller, when in use, is partially or fully suspended by hydrodynamic forces, which are generated between the interaction of the hydrodynamic bearing surface located on the embodied impeller and a complementary housing of the pump. The bearing surfaces in this embodiment occur on all of the surfaces directly opposed to the impeller. It should be noted that in this embodiment, the bearing surfaces located on the upper and lower surfaces of the impeller function, in use, to suspend the impeller axially in respect of the axis of rotation of the impeller. Whilst the bearing surfaces 56 located on the outer edge of the impeller 57 function, in use, to suspend the impeller 57 radially in respect of the axis of rotation of the impeller.

Preferably in this embodiment of the impeller 57, each blade has a generally triangular configuration, when viewed from a top or bottom view. The triangular configuration is created wherein the inner portion, being the portion closer to the center periphery of the impeller, of the blade is narrower relative the outer portion of the blade and the breadth of the blade increases as the radius from the center increases.

Please note that it is preferable, to rotate this impeller, when in use, by magnetic forces/moments. These magnetic forces may be generated by the interaction of permanent magnets implanted, embedded or otherwise encased within each of the blades. These permanent magnets are configured in such a way so as to interact with

electric coils mounted on or in the housing in a position so as to apply rotating moments to the impeller in a radial, axially or hybrid configuration.

In the embodiment depicted in figure 10, the impeller 57 may include the advantages of being easier to manufacture. This is mainly because the generally flattened configuration shown, as compared with impeller 45, may be capable of being easy to machine and manufacture.

The above descriptions only describes some of the embodiment of the present inventions and modification, it may be obvious to those skilled in the art that further modifications can be made thereto without departing from the scope and spirit of the present invention.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

Claims

1. A rotary blood pump including: a housing, wherein said housing includes a housing cavity, an inlet and an outlet; at least one support feature; an impeller, wherein said impeller includes at least one blade attached the support feature and positioned within said cavity and, when in use, said impeller is urged to rotate by rotating magnetic field and thereby pump blood from said inlet through cavity to the outlet, and wherein said support feature promotes dimensional stability within the impeller.
2. The pump of claim 1, wherein said support feature reinforces the dimensional stability of said impeller.
3. The pump of either claims 1 or 2, wherein said support feature includes at least one support ring.
4. The pump of any one of claims 1 to 3, wherein support feature includes two support rings.
5. The pump of any one of claims 1 to 4, wherein at least one support feature is attached to a position proximate to outermost point of a side of each blade.
6. The pump of any one of claims 1 to 5, wherein at least one support feature is attached to a position proximate to innermost point of a side of each blade.
7. The pump of any one of claims 1 to 6, wherein said impeller is at least partially hydrodynamically suspended, in use, within said housing cavity.
8. The pump of any one of claims 1 to 7, wherein said impeller includes at least one hydrodynamic bearing attached to an outer surface of said impeller.

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

9. The pump of claim 7, wherein said hydrodynamic suspension radially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

10. The pump of claim 7, wherein said hydrodynamic suspension axially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

11. The pump of claim 7, wherein said hydrodynamic suspension radially and axially suspends said impeller, in respect of an axis of rotation of said impeller, in use.

12. The pump of any one of claims 1 to 11, wherein said impeller includes at least one permanent magnet.

13. The pump of any one of claims 1 to 12, wherein said pump includes a three phase motor formed by mounting electric coils on or about said housing.

14. The pump of claim 13 wherein magnets which form part of the impeller are caused to rotate in the rotating magnetic field produced by the electric coils

15. The pump of any one of claims 1 to 13, wherein said pump is suitable for implantation within a patient

16. The pump of any one of claims 1 to 15, wherein said impeller includes a shaft.

17. The pump of any one of claims 1 to 16, wherein said pump is an axial flow pump.

18. The pump of claim 17 wherein said pump includes an underhung volute positioned proximate to the outlet,

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

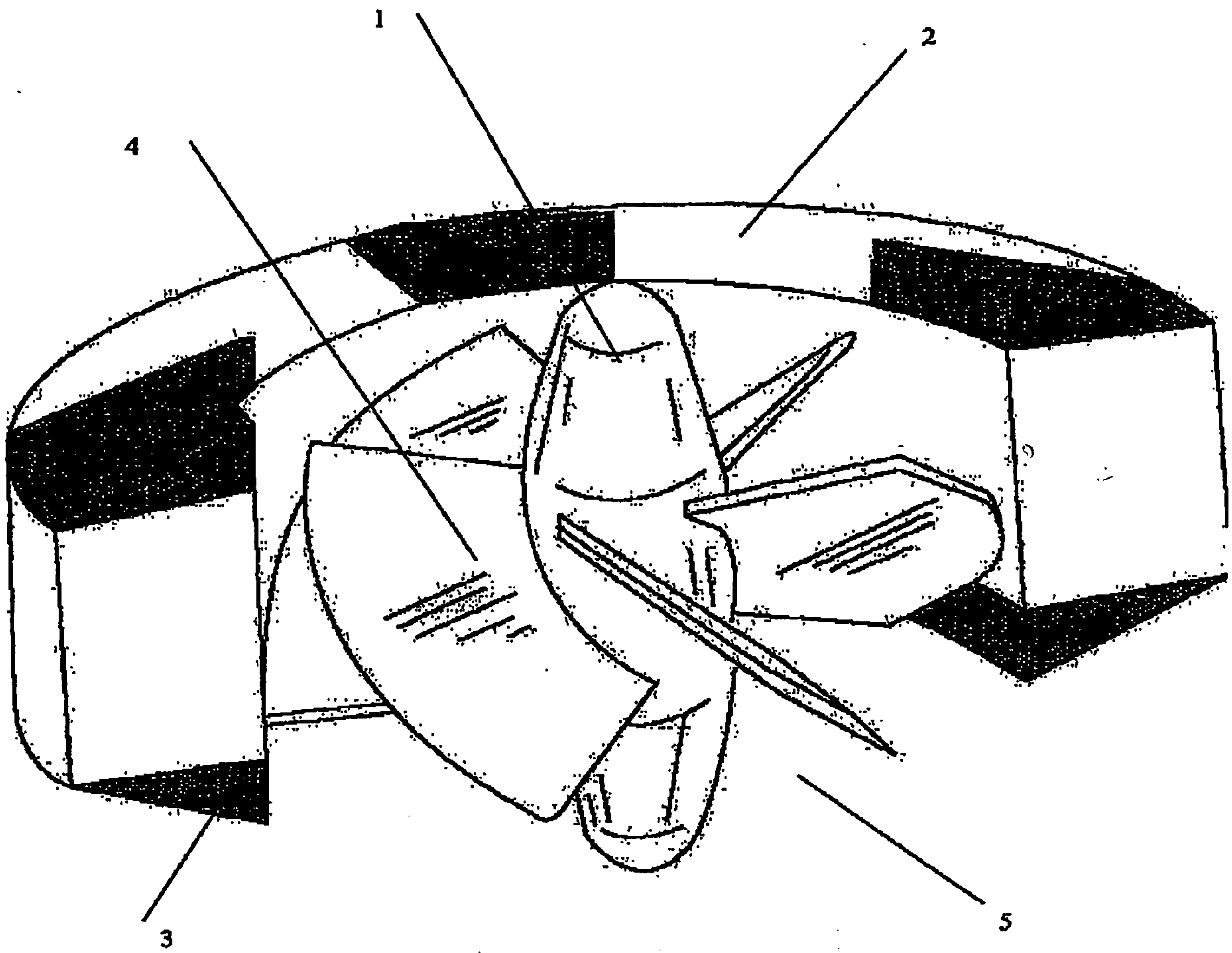

Figure 1

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

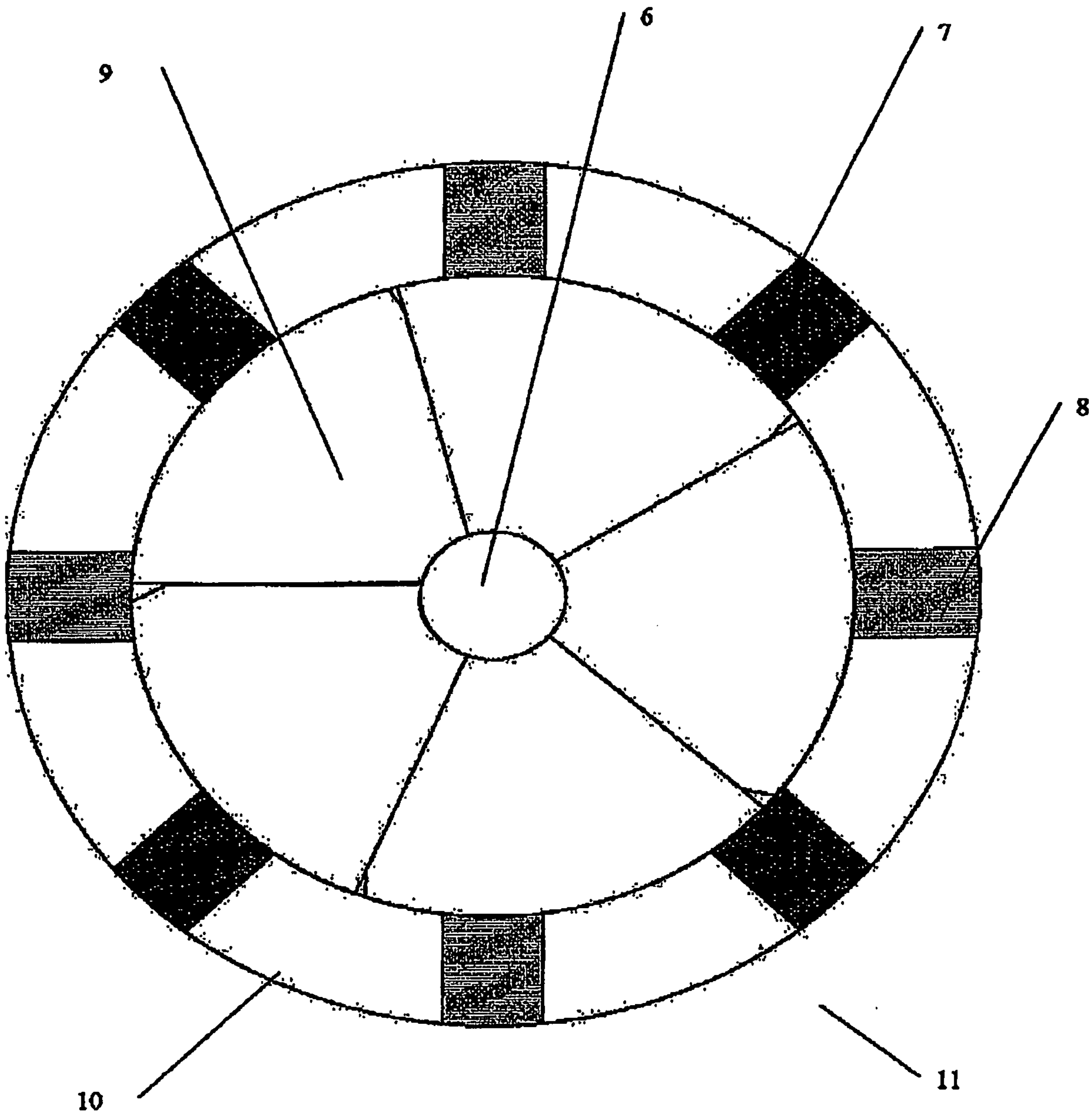

Figure 2

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

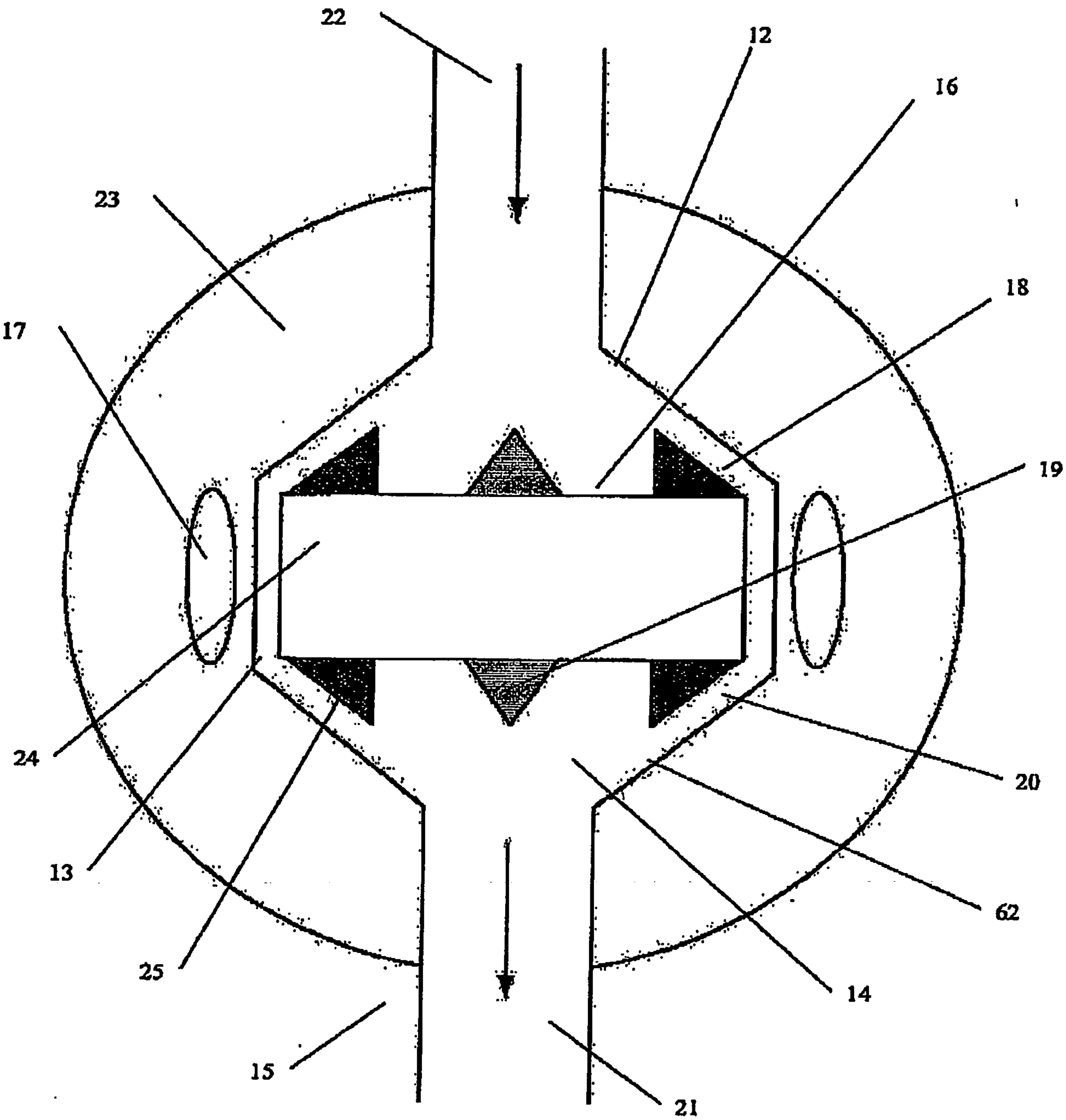

Figure 3

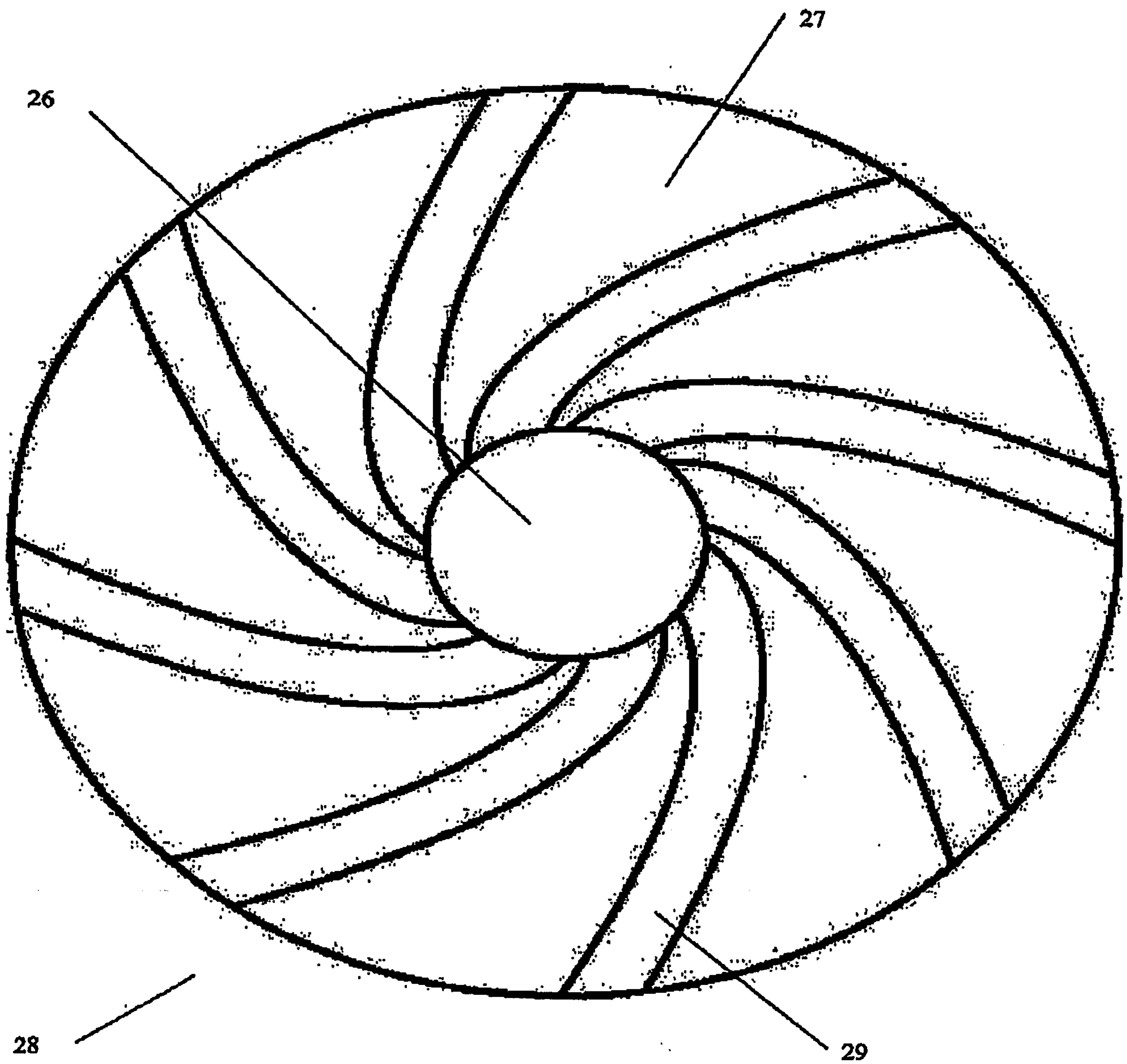

Figure 4

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

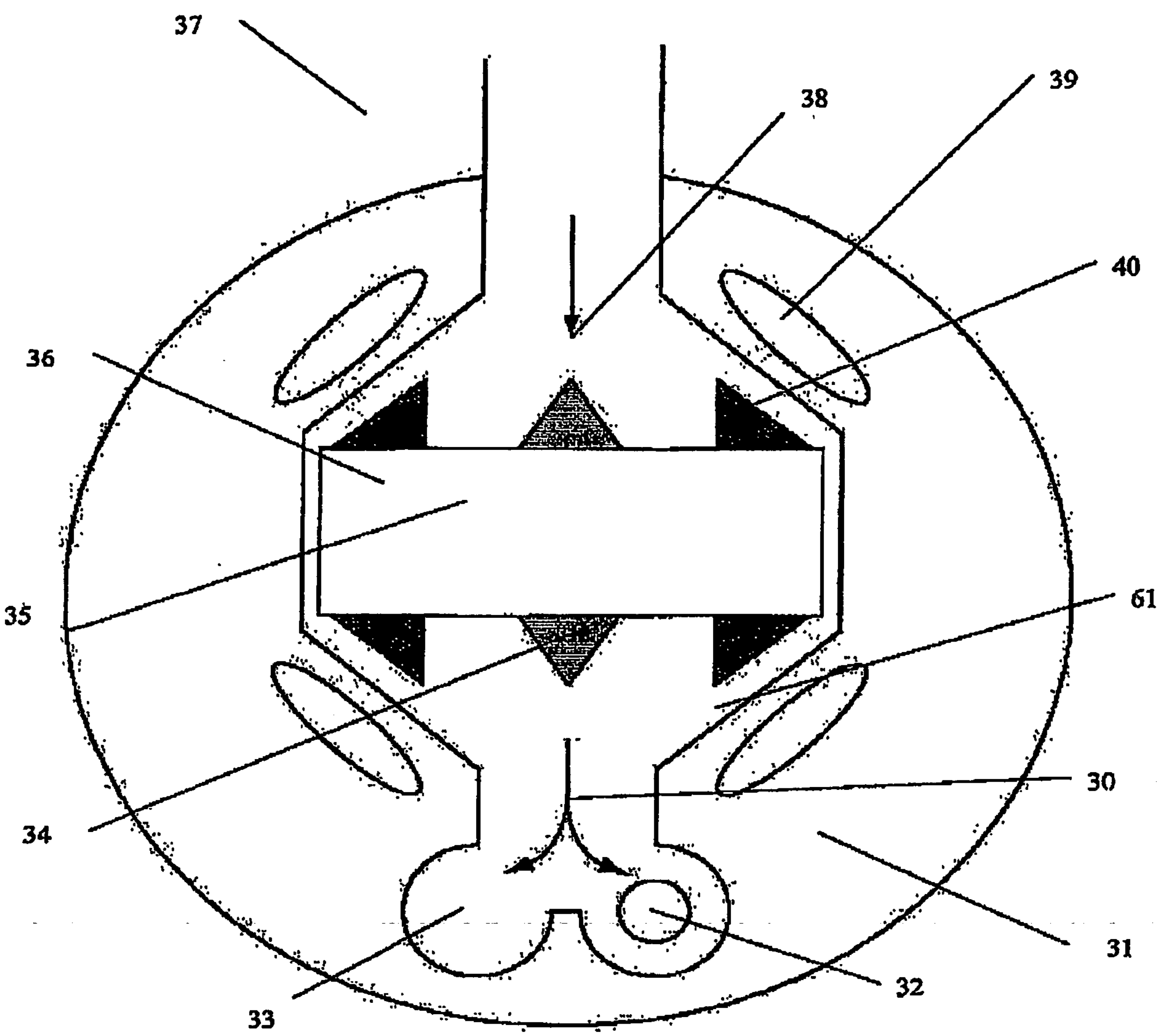

Figure 5

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

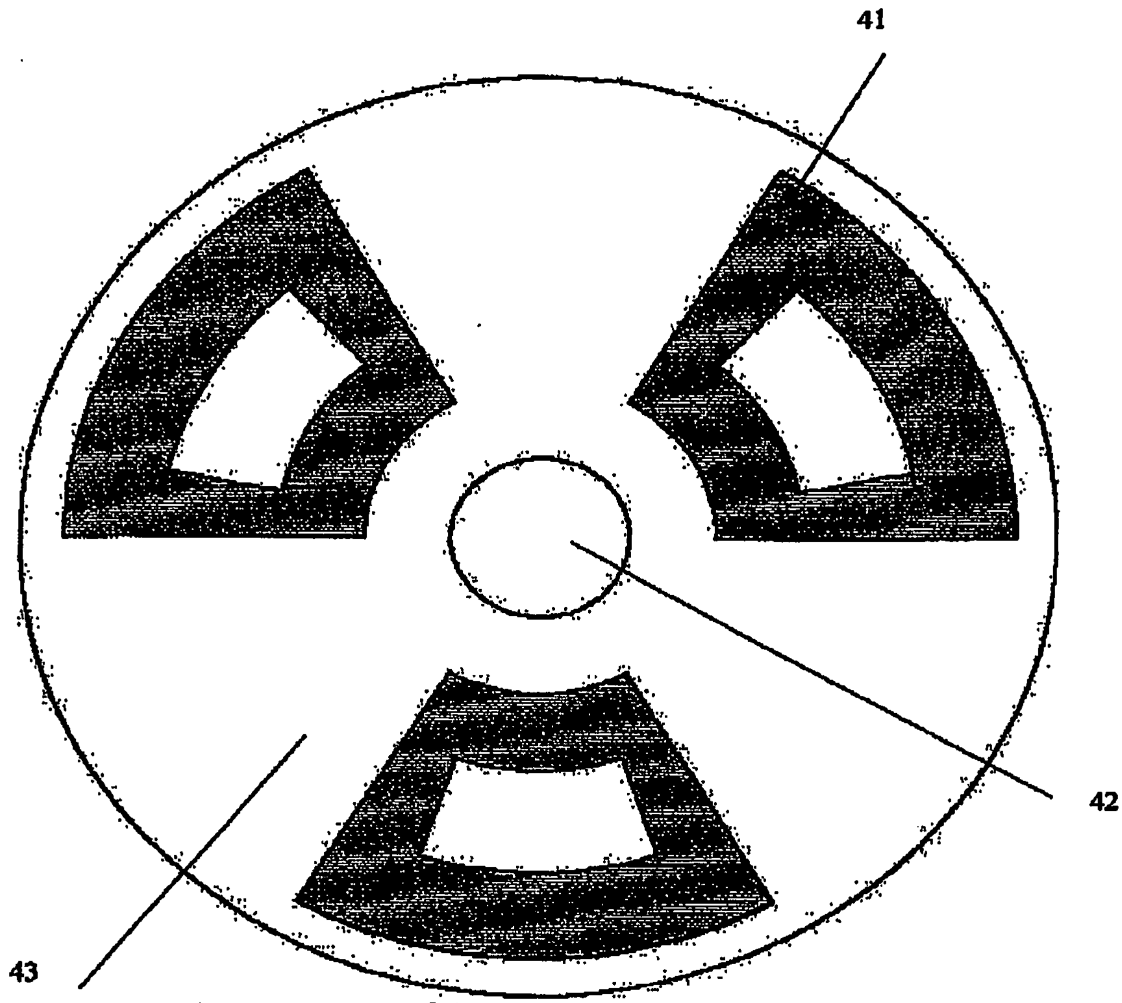

Figure 6

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

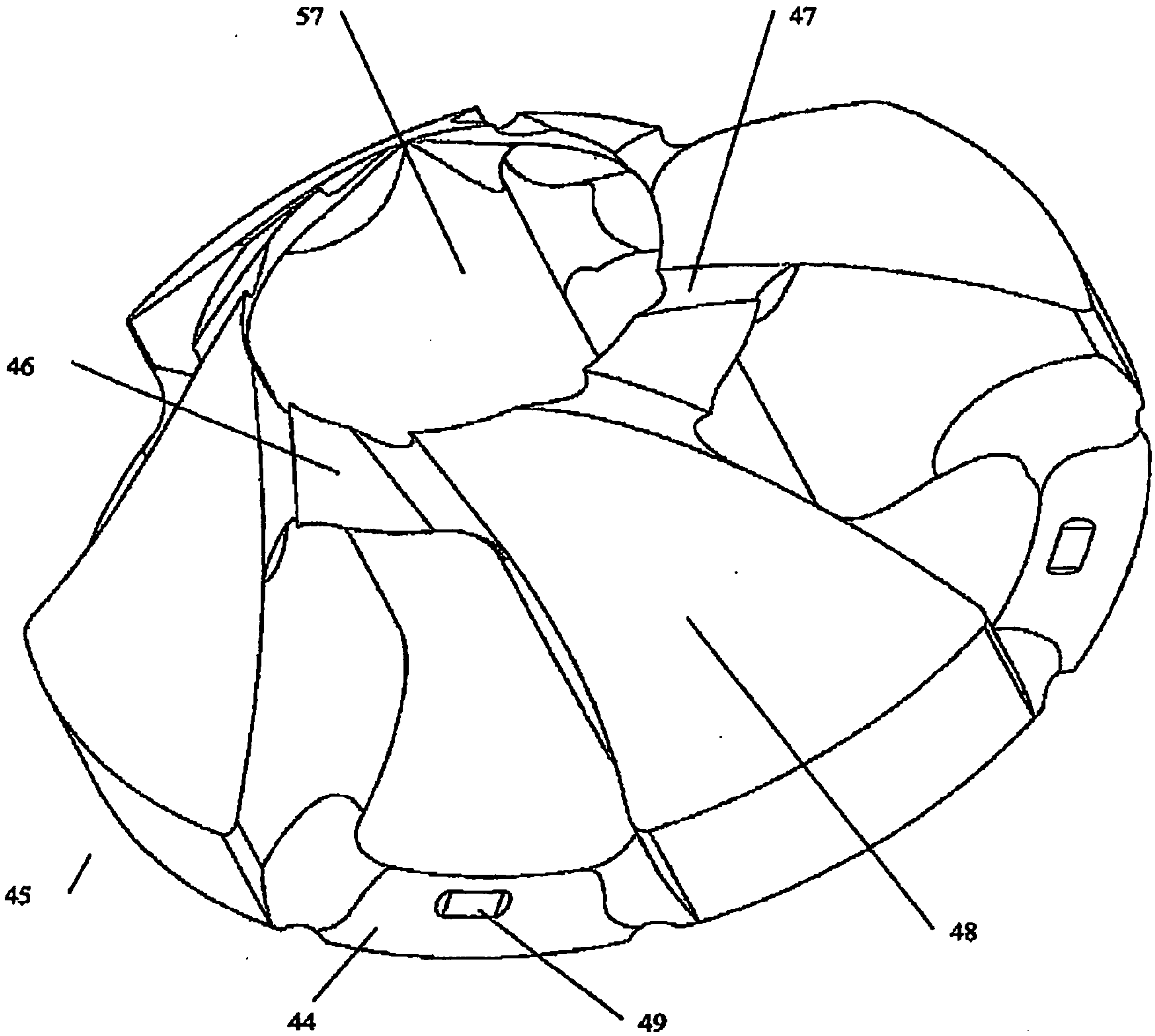

Figure 7

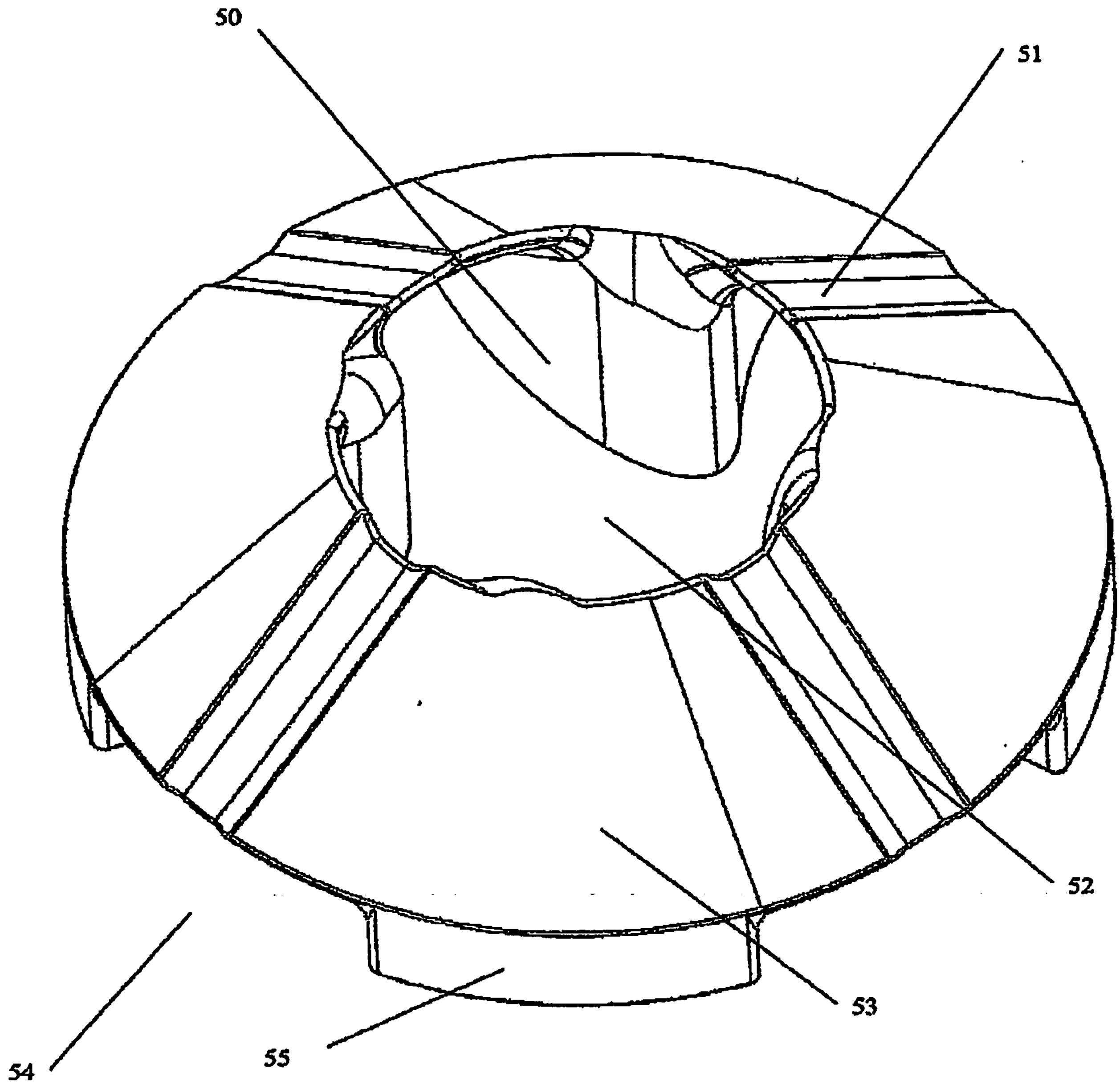

Figure 8

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

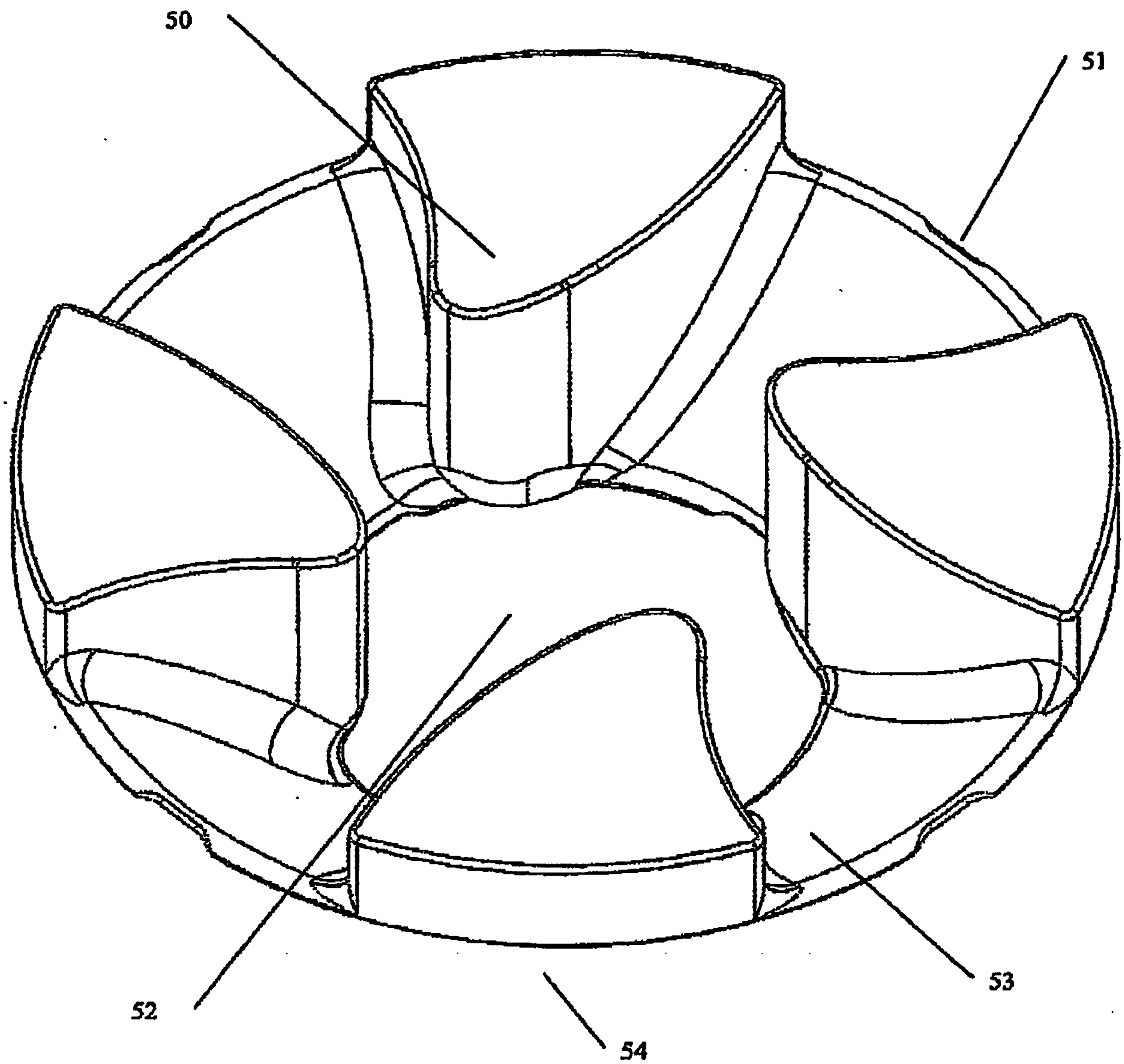

Figure 9

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

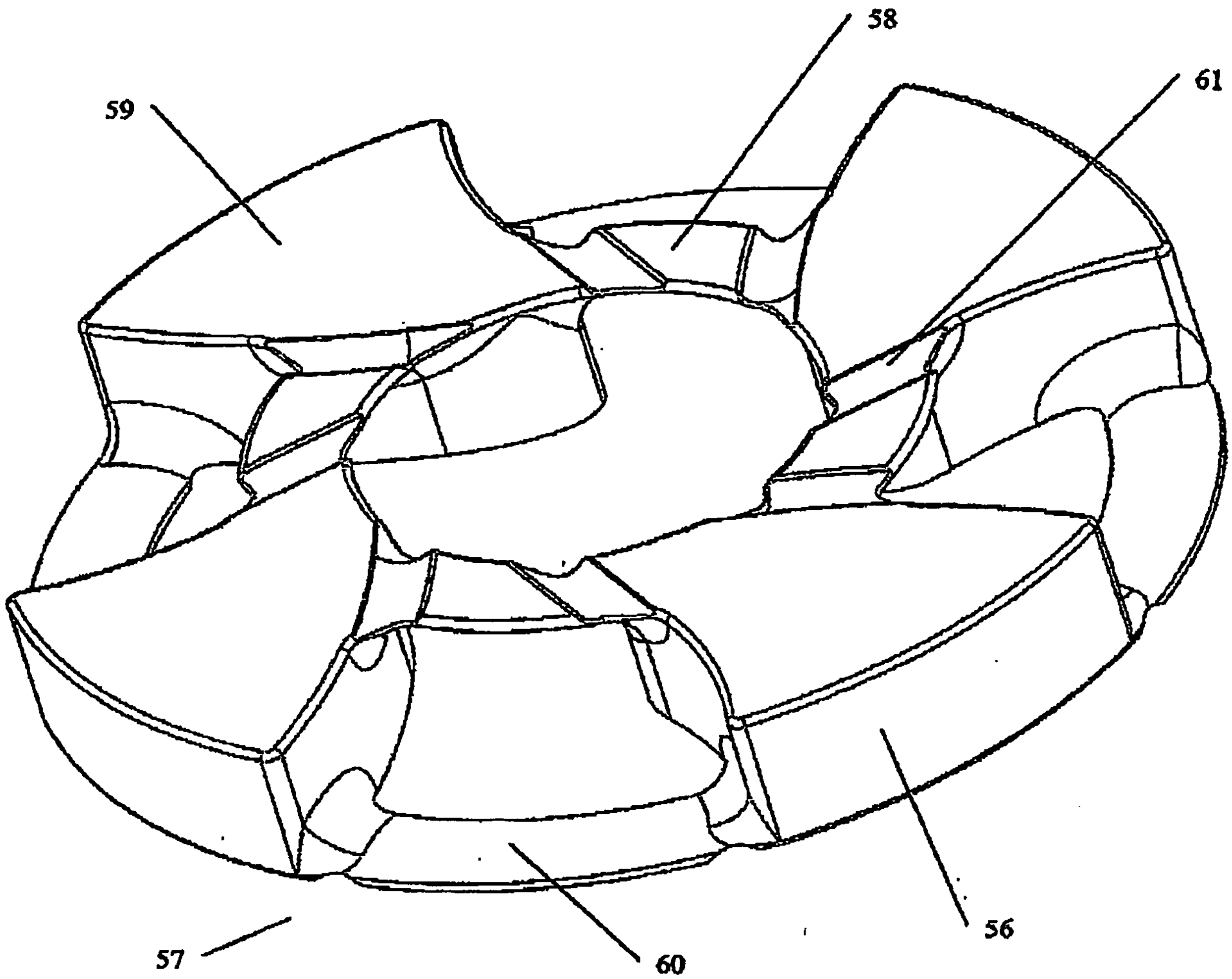

Figure 10

COMS ID No: SMBI-00447420 Received by IP Australia: Time (H:m) 23:42 Date (Y-M-d) 2003-10-09

Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/AU04/001379

International filing date: 08 October 2004 (08.10.2004)

Document type: Certified copy of priority document

Document details: Country/Office: AU
Number: 2003905511
Filing date: 09 October 2003 (09.10.2003)

Date of receipt at the International Bureau: 01 November 2004 (01.11.2004)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)